Chapter 28
Invasive Alien Plants in Protected Areas: Threats, Opportunities, and the Way Forward

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Abstract The potential threats posed by biological invasions are widely appreciated, but the state of knowledge and level of management of invasive alien plants in protected areas differs considerably across the world. Research done on nature reserves as part of the international SCOPE programme on biological invasions in the 1980s showed the vulnerability of natural or undisturbed areas to invasions. Subsequent work, including the chapters in this book, shows the serious situation regarding plant invasions that prevails in many protected areas. Many invasive plants have, or have the potential to, greatly lessen the potential of protected areas to achieve the things they were proclaimed to do – provide refugia for species,

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habitats and the ecosystem services that they sustain. This brief synthesis discusses some emerging insights from protected areas of varying kinds and sizes, from the Azores, Australia, Chile, East and South Africa, Europe, Galapagos, India, Mediterranean Islands, New Zealand, Pacific Islands and Hawaii, Southern Ocean Islands, United States of America and the Western Indian Ocean Islands. Work in some protected areas has led to well-developed management and policy frameworks. In others, important insights have emerged on invasion mechanisms and the impacts of invasions. Although there is awareness of invasive alien plants in most of the 135 protected areas mentioned in this volume, better and more focused actions are urgently needed. This requires, among other things, improved capacity to prevent invasions and to react promptly to new incursions, and increasing efforts to manage well-established invasive species. Research to improve the understanding of invasion dynamics is essential. Full species lists are available only for a group of well-known protected areas. Updating species lists and distribution data is crucial for successful long-term management, as are collaborative networks, research groups, volunteers, and improved accessibility to resources such as online databases. Efforts to lessen the science-management divide are especially important in protected areas. One reason is that managers are usually required to implement invasive alien plant control programmes as part of general protected area management activities, and in many cases lack the knowledge and support for effective science-based management solutions. Overcoming this barrier is not trivial and will require partnerships between local, municipal, regional and national-level organizations and international non-profit NGOs and donor organisations.

Keywords Biological invasions • Impacts • Invasive alien plants • Non-native plants • Protected areas

28.1 Introduction

Many books (e.g. Cadotte et al. 2006; Nentwig 2007; Davis 2009; Richardson 2011) and more than 800 journal articles per year for the last 4 years (Fig. 1.2 in Chap. 1 Foxcroft et al. 2014b) attest to the huge interest in biological invasions. Indeed invasion biology has grown rapidly to become a strong and vibrant field within the ecological and conservation sciences. The main aim of this book was to provide a deeper understanding of the extent and dimensions of invasive alien plants (IAPs) in protected areas (PAs) – the pillars on which many conservation efforts are built and rely. Although conservation measures outside formally protected areas are being given more attention (e.g. Ervin et al. 2010), many conservation aims can only be achieved in areas that enjoy special levels of protection. Protected areas are therefore usually seen as core conservation areas and afforded the highest priority to, for example, maintain functional systems and populations from which species may disperse. Biological invasions are widely seen as one of the major threats to biodiversity in general, and as chapters in this book indicate, in many places also directly to PAs. In many cases, the extent of invasions and the levels of impacts due to invasive species have exploded in recent decades. Traditional measures of protection and intervention do not appear to limit the impact of invasions within PAs. Another problem is that PAs are increasingly becoming embedded in a matrix of human-modified landscapes which is creating an increasingly sharp interface between 'natural' and highly modified ecosystems. Among other things, this creates a continuous source of propagules for invasion. It is also not only the physical location of PAs that affects potential threats. Protected areas do not always enjoy high priority for the allocation of financial resources and are, in many cases, expected to generate their own resources, usually through tourism. Within PAs, limited resources are increasingly stretched across many aspects of management. Invasive alien plants often end up low on the list of priorities, notwithstanding their ability to cause impacts on basic ecosystem processes, for example biogeochemical cycling and fire (Chap. 2 Foxcroft et al. 2014a) and shifting PAs into alternative states that even active restoration may be unable to reverse (Chap. 27 Larios and Suding 2014).

The chapters in this book were grouped into three parts which sought to: (i) synthesise insights on plant invasions in PAs and integrate these with current models and theories of plant invasion ecology, (ii) determine the status of knowledge of IAPs in PAs, and (iii) determine key knowledge areas for informing the development of successful management strategies.

In the first part we asked authors to explore ways in which PAs could and have provided unique opportunities for gaining insights into broadly encompassing themes. Chapters in this part also show how work in PAs has led to advances in the field. These topics include the role of PAs for developing further understanding of plant invasions and succession in natural systems, impacts of IAPs, the invasion of mountain ecosystems and large scale monitoring programmes.

The 14 case studies in Part II aimed to capture experiences from PAs in different settings and regions. These focus on a range of island systems (e.g. Pacific, Western Indian, Southern Ocean; Mediterranean) and PAs in continental regions of Africa, Australia, Chile, Europe, the USA and other areas. The contributions synthesise diverse insights on IAPs from PAs of different kinds and sizes in many different environmental settings, and detail what has been learned from research and management experiences in these areas. The case studies also examined the specific contexts of the systems and their unique attributes, and explore the extent to which aspects such as modes and pathways of introduction and dispersal, impacts on biodiversity, the role of natural disturbance regimes and anthropogenic disturbance, define natural laboratories for examining questions that cannot easily be studied in other regions.

The management chapters round off the book by collating insights from general approaches, integrating them with experiences and context-specific examples. This section does not present a manual on how to clear IAPs, or lists of the techniques and herbicides to apply, as these are well documented elsewhere. Rather, the chapters provide in-depth syntheses of specific fields (e.g. biological control, Chap. 26 Van Driesche and Center 2014), examine the arguments for well-known but under-implemented approaches (e.g. eradication, Chap. 25 Simberloff 2014), while others offer novel methods for implementing actions within the PA context (rehabilitation, Chap. 27 Larios and Suding 2014; outcome-based planning, Chap. 23 Downey 2014; prevention, Chap. 21 Meyerson and Pyšek 2014). Two chapters discuss the challenges of managing IAPs in PAs more generally (Chap. 22 Genovesi and Monaco 2014; Chap. 24 Tu and Robison 2014). Also emphasised is the role of PAs beyond their borders, stressing the need to improve prevention and prompt response to new incursions. Collectively these chapters provide PA managers, conservation biologists, invasion biologists and others with collated knowledge on a wide variety of elements required for formulating comprehensive approaches to managing IAPs.

28.2 Key Outcomes

In this chapter we focus on three key themes: (i) impacts, (ii) management and (iii) the role of PAs as focal research sites. The outcomes of these chapters provide interesting examples on how the knowledge collected in PAs and the growing understanding of impacts caused by IAPs, can guide more effective management of invasions.

28.2.1 Impacts

Impacts of IAPs have been demonstrated in almost all regions and a large number of examples show the severity of change that is likely if invasions continue unabated. Although the quantification of impacts on species, communities, landscapes, habitats, ecosystem dynamics and services is difficult to elucidate, a surprising amount of work has been done in PAs (Chap. 2 Foxcroft et al. 2014a). In some cases, complete switches in ecosystem states have been observed that are unlikely to be reversed even if the invader is removed ('legacy effects' e.g. D'Antonio and Meyerson 2002). While exaggerated 'scare tactics' are certainly not appropriate, this kind of information has the potential to illustrate the severity of problems that could occur more widely if IAPs are not effectively managed. Finding ways of presenting such information accurately, but in ways that are also compelling to the public and decision makers, is a key challenge.

At the same time that invasion science has started moving away from a focus on single species to ecosystem level alterations (Chap. 25 Simberloff et al. 2014), conservation biologists have also started shifting their focus from single species or habitat conservation towards a more ecosystems based approach (Ostfeld et al. 1997). Many organisations or individual PAs were not necessarily designed within this context, and in some cases PAs were especially designated as species-specific reserves (e.g. Kaziranga National Park established for the one-horned rhinoceros, *Rhinoceros unicornis*, and now threatened by IAPs altering feeding areas, Chap. 12 Hiremath and Sundaram 2014). In such cases focusing research on individual IAPs most likely to impact the species of concern is appropriate. In some cases assessing the impacts of IAPs on particular taxa as indicator species (commonly beetles and spiders, see examples in Chap. 2 Foxcroft et al. 2014a) can serve as indicators of wider ecosystem-level changes. Research on less visible impacts, for example plant-soil nutrient dynamics, are required to understand whole-ecosystem energy budgets and function (Ehrenfeld 2010), the alteration of which can lead to profound changes to PAs. Integration of species- and ecosystem-based approaches (Likens and Lindenmayer 2012) in future may however provide interesting and novel approaches for understanding and managing biological invasions.

28.2.2 Management Approaches

Biological invasions are a good example of what has come to be known as 'wicked problems' (Conklin 2005). They are inherently complex and there is no single, easy or correct answer to management problems. There are numerous stakeholders, from local to global scales, with different perceptions and personal values, and economic incentives (e.g. increasing international trade), which greatly complicate the formulation of common goals (Chap. 4 McNeely 2014).

There has been a shift away from a focus on techniques for controlling IAPs to approaches for defining priorities, examining when and where active or passive restoration is required, defining the appropriate setting and deciding on how to achieve conservation outcomes. Further innovations are needed to guide the implementation of control measures with shrinking resources. Collaborations and knowledge sharing can lead to improved IAP management. Strategies need to focus on determining biodiversity areas most at risk and optimising approaches for conservation of these, rather than focussing on the control itself (Chap. 23 Downey 2014). Many hurdles need to be negotiated in formulating and implementing a successful IAP management programme; many sources of information are now available to assist in the development of effective plans. Once the foundations of a management approach have been laid, the process can evolve as more resources become available, and knowledge and management expertise is developed (Chap. 22 Genovesi and Monaco 2014; Chap. 24 Tu and Robison 2014).

Although IAP management programmes are often built into PA management plans, long-term success depends on whether the affected system can recover after control, or whether further intervention is needed to aid recovery (Chap. 27 Larios and Suding 2014). Preventing the introduction and spread of IAPs into PAs is an essential management strategy, even in the current era of global change. Management of invasion pathways and propagule pressure is an emerging preventative measure (Chap. 21 Meyerson and Pyšek 2014). While the literature abounds with information on eradication as the most effective strategy for managing alien plant invasions, many managers and scientists remain pessimistic about the feasibility of eradication. However, if well-funded, planned and implemented, once-off eradication campaigns can make projects that appear impossible a reality (Chap. 25 Simberloff 2014). In regions where sufficient resources are unlikely to be procured over the long term, biological control should be a key component of the overall management strategy. Once tested and released, biocontrol agents can be used over large areas and in places that are difficult to reach, at low cost (Chap. 26 Van Driesche and Center 2014). There is considerable scope for sharing of experiences with biological control across PAs.

Monitoring is one of the most important aspects of an overall IAP management programme, and probably also in PA management generally. Monitoring is needed to detect incursions by new species and populations (surveillance), track the status and extent of invasions, determine progress of control operations, and assess the outcome of eradication attempts and long-term maintenance programmes. Large PAs, however, present particular problems for effective monitoring, due to need for robust, cost effective, but rapid assessments. Protected areas provide opportunities for developing these concepts, and to test their efficacy in the field, for example using data from routine ranger patrols that are available in many PAs (Chap. 5 Hui et al. 2014).

28.2.3 Protected Areas as Science Hubs

There are many examples where PAs have formed the nucleus of science research programmes (e.g. Hawaii, Chap. 15 Loope et al. 2014; Galapagos, Chap. 16 Gardener et al. 2014; South African National Parks, Chap. 7 Foxcroft et al. 2014c), and where context-specific science can be of direct relevance to local PA management authorities. Motivations for forming research hubs with PAs range from, for example, (i) provision of good logistical support, (ii) employment of scientists within PAs actively carrying out studies, and forging collaborative programmes with other institutions, (iii) at the request of PA managers for support, or (iv) interest by scientists in a particular area and/or problem, and (v) in studying ecological processes in relatively undisturbed environments.

In Haleakala and Hawaii Volcanoes NPs (Chap. 15 Loope et al. 2014), species lists (more than 300 alien plants in Haleakala and 600 in Hawaii Volcanoes) and distribution data have been extensively assessed. Much research has been carried out in this PA, providing a very detailed understanding of a few species (*Morella faya*, faya tree; *Hedychium gardnerianum*, Kahili Ginger), a good practical understanding of impacts for the most threatening invaders, and helping to inform management efforts (Table 28.1). In another example, the Charles Darwin Research Station, Galapagos National Park and other institutions, have collaborated to develop a scientific basis to guide management of IAPs in Galapagos (Chap. 16 Gardener et al. 2014). The programme comprised a number of components including: baseline inventories, quarantine development, while the science programme focused on, for example, impacts of *Cinchona pubescens* (quinine tree) and *Rubus*

Table 28.1 Examples from selected protected areas as indicators of the status of plant invasions

Protected area	Species lists and distribution	Level of management	Level of scientific input/involvement	Understanding of impacts
Amani Nature Reserve, Tanzania (Chap. 8 Hulme et al. 2014)	Detailed species lists and distribution data.	No existing plans to manage invasive species in Amani Nature Reserve or the sources of invaders in Amani Botanical Garden.	Work on propagule pressure as major driver of invasion. Role of Amani Botanical Garden as a source of invasive species. Weed risk assessment tools (e.g. Australian Weed Risk Assessment).	Impact of *Maesopsis eminii* on native species recruitment and succession.
Biligiri Rangaswamy Temple Tiger Reserve, India (Chap. 12 Hiremath and Sundaram 2014)	Long-term monitoring of *Lantana camara* spread and changes in density.	Ad hoc small-scale *L. camara* removal by uprooting, and cutting-and-burning, but no systematic removal and restoration plan in place.	Work on drivers of invasive species spread. Experimental work on different weed removal techniques to assess relative efficacy and to determine barriers to native species restoration.	Effect of *L. camara* and *Chromolaena odorata* growth on species diversity, regeneration and stem density of tree and shrub layer.
Fiordland NP, New Zealand (Chap. 14 West and Thomson 2014)	Detailed species lists and distribution data exist for coastal locations and many specific locations within the NP.	Site-specific control until the mid-1990s when control to zero-density was initiated for a number of specific species, e.g. *Ammophila arenaria*, *Ulex europaeus*, *Cytisus scoparius*.	Field staff have access to advice from technical and scientific experts within the Department of Conservation as well as externally from research agencies and universities.	Impacts of some species are understood well, e.g. *U. europaeus*, *A. arenaria*, *Salix fragilis*, but understood less well for others, e.g. *Hypericum androsaemum*.
Galapagos NP Service, Galapagos (Chap. 16 Gardener et al. 2014)	Systematic once-off survey of inhabited areas adjacent to protected areas. Ad hoc collection in protected areas. To date, a total of about 871 alien species and 33,000 records.	On-going management since early 1980s. Between 2005 and 2010, 17 projects on five islands covering 11 species (~2,000 ha).	Since mid-1990s pragmatic research based approach used to: (i) understand the problem; (ii) developing management tools; and (iii) address the challenges of implementation.	Impacts of *Cinchona pubescens* and *Rubus niveus* on biodiversity and ecosystem function. Role of alien plants in pollination and seed-dispersal networks.

(continued)

Table 28.1 (continued)

Protected area	Species lists and distribution	Level of management	Level of scientific input/involvement	Understanding of impacts
Haleakala NP, Hawaii (Chap. 15 Loope et al. 2014)	Species and distribution data well developed (> 300 alien plants).	Modest within-Park control efforts, hindered by remoteness of high biodiversity rainforest. Substantial collaborative island-wide strategic proactive efforts to contain or eradicate encroaching invasions from outside the NP.	Research has helped inform and prioritise management efforts.	Good practical understanding of impacts for the most threatening invaders.
Hawaii Volcanoes NP, Hawaii (Chap. 15 Loope et al. 2014)	Species and distribution data well-developed and up-to-date (> 600 alien plants of which > 400 are naturalised).	Intensive strategic focus on alien plant control in 'Special Ecological Areas' as well as eradication or containment of selected species park wide.	Research has informed and helped to prioritise management efforts. Biological control research has been substantial; benefits are as yet small but opportunities may be large.	Impact of a few species exceptionally well understood through research (*Morella faya*, *Hedychium gardnerianum*, grasses), good practical understanding of others.
Kakadu NP, Australia (Chap. 9 Setterfield et al. 2014)	On-going surveys and collection of alien plant occurrence data.	Two dedicated alien plant control teams (*Mimosa pigra* and grassy weeds). Additional management undertaken by rangers.	Research undertaken by external agencies (universities, CSIRO) in collaboration with NPs. Major research project currently on predicting and managing spread of floodplain grassy weeds. Previous research on *Salvinia molesta* and *M. pigra*. Research Committee oversees research activity.	A major project has been completed in Kakadu NP on impact of *Urochloa mutica*.

Kruger NP, South Africa (Chap. 7 Foxcroft et al. 2014c)	On-going surveys, species list well developed (~350 alien plants). Distribution data covers entire park, with about 30,000 point records.	Before 1996, small but long-term control efforts. After 1996, substantial programme with at times several hundred employees, funded by Working for Water. Main focus on woody shrubs along main rivers, aquatic species and *Opuntia stricta*.	Since 2001, full time invasion biologist appointed. Work on biocontrol post release evaluation, risk analysis, ornamental plant invasions and boundaries as barriers to invasion to support management efforts.	Mostly anecdotal evidence. Some research done on impacts of *O. stricta* on biodiversity indicators.
Table Mountain NP, (Chap. 7 Foxcroft et al. 2014c)	On-going surveys, species lists well developed (~239 alien plants). Fine scale distribution data covers most of the park.	Long history of control efforts, although initially unsuccessful. In the last 15 years Working for Water has supported a substantial programme, investing about US$1,7 million annually.	Much research has been conducted in TMNP generally, with increasing focus on IAPs. Partnerships between academic researchers, managers, policy makers and funders facilitated an integrated strategic approach to implementation of control programmes.	Work has focused on IAPs changing fire behaviour, erosion, and potential extinction of rare and endangered species.
Western Indian Ocean Islands (Chap. 19 Baret et al. 2014)	Lists of all alien plant species present within terrestrial protected habitats.	Varies according to countries.	From early detection and rapid response, to on-going eradication of large propagation plants.	Variable between country and type of protected areas.

niveus (Ceylon raspberry) on biodiversity and ecosystem function and the role of IAPs in pollination and seed-dispersal networks (Table 28.1).

In general, international collaborative networks provide opportunities for exploring the impacts and role of IAPs in different settings, and achieving a broader synthetic understanding of invasions. Some of these recent efforts have been conducted with a strong conservation focus. For example, many mountain systems worldwide have been designated as national parks and reserves (Spehn et al. 2006), and one third of the world's PAs are in mountainous regions (Chap. 6 Kueffer et al. 2014). Mountains are important for people, biodiversity and for providing ecosystem services, but they are often considered as having a low risk of invasion. However, a global network (MIRN) examining IAPs in 11 mountain ranges showed that mountains are not inherently more resistant to invasion. Moreover, future risks will increase with global warming and continuing human land use and expansion (Chap. 6 Kueffer et al. 2014). It is important to link these focused projects to the global efforts to increase the inter-operability of information systems on IAS, such as the Global Invasive Alien Species Information Partnership, launched by the Convention on Biological Diversity (Chap. 22 Genovesi and Monaco 2014).

28.3 Glaring Gaps and Serious Shortcomings

Useful insights and experiences in at least some facets of policy, management, or scientific investigation of IAPs emerged from PAs in all regions. However, some aspects emerged as fairly general problems or gaps, which are impeding the implementation of effective IAP management programmes. Such issues relate to incomplete data on IAPs, poor implementation of research outputs in management programmes, and the shortage of financial resources.

28.3.1 Species Lists and Distribution Maps: The Urgency of Systematic Surveys

Inventories of IAPs and of the key correlates of invasions, including geographic data, are crucial requirements for robust management plans. While the situation is improving, some areas still lack even basic information on invasive plants in PAs, for example in many African PAs (Chap. 7 Foxcroft et al. 2014c). This is in accordance with global distribution of knowledge of invasions in general. A recent assessment of regional contributions to invasion ecology found a low representation of developing countries, and Asia and Africa (with the exception of South Africa) were found to be markedly understudied (Pyšek et al. 2008). In a literature review of ecology and biodiversity conservation, only 15.8 % of all published papers related to alien species had authors from developing countries, and only 6.5 %

had authors solely from developing countries (Nuñez and Pauchard 2010). In general, the number of documented invasive species also gives a significant underestimate of the magnitude of the problem, because its value is negatively affected by country development status (McGeoch et al. 2010). However, surprisingly also in Europe, one of the most intensively studied continents (Pyšek et al. 2008), systematically collected information on IAPs in PAs does not exist (Chap. 11 Pyšek et al. 2014).

The paucity of essential baseline information, including species lists and distribution data impedes development of both local and regional scale prevention, management and monitoring approaches (McGeoch et al. 2012). Potential errors common in compiling lists of alien species are often unrecognised (McGeoch et al. 2012) and need to be taken into account as these data start being collected and compiled. This uncertainty can be compounded as the lists are used at different scales and for different purposes, for example, local scale management vs. reporting globally under the CBD Biodiversity targets across regions (Pyšek et al. 2008). While many areas are currently developing or expanding such datasets, cognisance of the potential errors and future use of the data from the outset will greatly increase the value of the data. A number of potential errors that can lead to uncertainty in IAP data include obtaining globally comparable data for individual PAs, non-systematic research, human error and taxonomic issues resulting in species misidentification, and variations in criteria applied to designate species as invasive (McGeoch et al. 2012). While some level of uncertainty is likely to be unavoidable, when determining the primary use of the data, strategies for reducing the level of errors need to be included.

While many regions have species lists, albeit usually incomplete and often only considering the most problematic and visible invasive species, there is generally an absence of distribution data, or where present, it is poor. Such information is essential for developing management and monitoring programmes. A number of tools that facilitate collection of spatial data are becoming more readily available, including free software that can be customised to the needs of a particular PA (e.g. CyberTracker, Kruger and MacFadyen 2011, and Geoweed, http://geoweed.org).

Not only is collection of data important, but data warehousing – a complex process – needs to be carefully managed to ensure that data are updated and readily available. A number of approaches are already in place in various regions and could serve as model systems for PAs, or by including specific PA-related modules into existing structures. Some examples are the DASIE project (Delivering Alien Invasive Species Inventories for Europe; DAISIE 2009; http://www.europe-aliens.org), CAB International's (CABI) Invasive Species Compendium (www.cabi.org/ISC), the IUCN Invasive Species Specialist Group Global Database (http:://http://www.issg.org/database), the South African Plant Invader Atlas (SAPIA, Henderson 1998; http://www.agis.agric.za/wip), and a number of freely available, customisable databases (e.g. Pl@ntnote; http://www.plantnet-project.org/page:tools?langue=en). However while these tools can be effective in developed countries where the required infrastructure is available, in developing countries access to internet based data is often problematic and approaches for overcoming these challenges need to be sought. These may be alleviated, at least to some extent, through collaborative networks.

28.3.2 Bridging the Science–Management Divide

While the scientific aspects of biological invasions are comparatively well understood, the extent to which this science is problem focused, and relevant for policy makers and managers, has been questioned (Esler et al. 2010). Although it is generally acknowledged that scientists and managers must work more closely together, this is perhaps especially important for PAs, because the managers are often based in remote areas, without the necessary skills and awareness, have many other responsibilities, or are trying to implement management programmes without adequate professional support.

Collaborative networks can help to consolidate information in suitable repositories or to facilitate links and access between data and information repositories, and also between members to share ideas and help each other. A number of agencies and organisations are already involved in various management efforts in different regions, for example the Mountain Invasion Research Network (Chap. 6 Kueffer et al. 2014) and Global Island Plant Conservation Network (Chap. 19 Baret et al. 2014). The development of a regional inter-agency collaborative network focusing on invasive species in PAs is likely to be better positioned to attract funding and enlist support from experts. Perhaps formal networks (e.g. the IUCN SSC Invasive Species Specialist Group and the IUCN World Commission on Protected Areas) can help stimulate or form collaborative networks where they would be useful, even if only through bringing role players together. Similarly, the coordinated research programmes launched by the European Union may present opportunities to overcome the lack of data from PAs across the continent, by including such a theme into European-wide proposal calls, and forming an international collaborative network.

28.3.3 Resources: The Ubiquitous Problem

The resources available for IAP management in PAs are, in most cases, inadequate to implement actions that are deemed necessary to reduce the abundance and density of invasive plants and manage their impacts. This is partly due to the many demands being placed on the limited resources available for PA management in general. Although not unique to PAs, but perhaps felt more acutely in the conservation sector, is the availability of resources across countries and regions of the world. For example, Africa (with the exception of South Africa) is probably at this stage unable, and is in the future unlikely to be able, to provide the resources for managing IAPs at anywhere near the levels that will be necessary to prevent many invasive species from becoming widespread and having major impacts.

Overcoming these constraints in a time of global financial austerity is a huge challenge, but the case studies reported in this book show how improved, science-based planning can help to make the best use of available resources. In many cases, solutions lie in sagacious project management, for example by applying objective decision-making tools for prioritizing action, and clever integration of prevention and other forms of management into overall management plans for PAs. Also, partnerships between local, municipal, regional and national governments and NGOs, and international non-profit or donor organisations, will need to be included in any management programme.

The availability and use of technology, whether for management or science, varies considerably, although not always necessarily in regions or countries as a whole. Fortunately, additional support has been provided for management in some PAs through interventions of non-profit organisations. Science-based associations have often developed through academic – government partnerships, or international – local scientific collaboration, where the country does not have the expertise and is otherwise unable to implement various technologies. This also fulfils the role of knowledge transfer.

It is important that case studies on management programmes (prevention, eradication, control, mitigation of impacts, etc.) are compiled and assessed, and that key lessons are circulated. Such insights are unlikely to appear in scientific journals because of the lack of rigorous experimental designs, non-standard methods, and the lack of incentives to spend time to publish such work. For this reason these data and information should be organised and made available online, for example integrating the different IUCN knowledge products such as the Red List, the Global Invasive Species Database, and the World Database on Protected Areas (www.wdpa.org). Integrating data on native and invasive species, as well as on the features of PAs, would provide extremely helpful information to managers.

28.4 Protected Areas as Natural Laboratories: Unique Opportunities

Protected areas have many features that make them ideal outdoor laboratories. Some aspects are unique to PAs due to the kinds of management interventions they experience, for example, from actively patrolled to unprotected/extensively utilised, and intense to laissez-faire management approaches. We highlight some features associated with PAs that may provide for interesting research opportunities.

- The range in sizes of PAs, from small nature reserves covering a few hectares to those covering millions of hectares. Also, the global distribution and variety of geographic and environmental features of PAs, and from islands to mountains, all provide many opportunities for comparative work across multiple scales. These attributes can provide opportunities for identifying general determinants of invasions in relatively undisturbed environments.

- The management approaches of PAs provide many unique settings. For example, many PAs in East Africa are unfenced, have no (or little) artificial water provision, and some have been studied for decades (e.g. Serengeti NP, Sinclair et al. 2008). In contrast, Kruger NP is fenced, has numerous artificial water points, and has also been well studied for several decades (Du Toit et al. 2003). Protected areas have been proclaimed at different times, have different histories and fall in different categories (e.g. one of the six IUCN PA classification categories). Such features provide outdoor laboratories for research of processes that may not be available elsewhere, where causes of local patterns and specific mechanisms of particular invasions can be addressed.
- It is reasonable to assume that PAs should have had significantly lower rates of intentional introductions of ornamental alien plants. In one of the world's oldest national parks (Kruger NP, South Africa), ornamental plants accounted for a large number of the alien plant species in the park. Ornamental plant use in and adjacent to PAs could thus be an important pathway of invasion and an important area to focus management attention (Foxcroft et al. 2008).
- The interaction of fire with many IAPs has induced radical ecosystem-level changes in many regions, including PAs (Brooks et al. 2004). Fire is an integral part of many, although not all, grassland and savanna ecosystems; interactions between fire and other factors have evolved over millennia, continuously adapting the structure, biodiversity and function of these systems (Bond et al. 2005; van Wilgen et al. 2003). The interaction of fire with certain alien plant species can create self-reinforcing feedback loops which drives rapid invasion, as has happened in northern Australia with *A. gayanus* (Rossiter et al. 2003; Setterfield et al. 2010; Chap. 2 Foxcroft et al. 2014b). In another example, a large-scale experiment in Hluhluwe-iMfolozi game reserve, fire interacted with conventional control actions, inducing a shift from woodland dominated, to grass-dominated systems (te Beest et al. 2012). Changing fire regimes (e.g. due to increased ignition events caused by human activities, changes in climate and vegetation) could alter the trajectories of invasions in many ways. Changing perceptions of the role of fire as a management tool will also change options for managing IAPs in many PAs.
- Tourism has been shown to be correlated with increased plant invasions (e.g. Usher 1988; Macdonald et al. 1989; Lonsdale 1999; Chap. 18 Brundu 2014). Many regions rely on tourism and associated economic benefits for financial support beyond PA boundaries (Christie and Crompton 2001; Eagles et al. 2002; Naughton-Treves et al. 2005). Much work remains to be done to improve our understanding, and where necessary, reduce the facilitative role of certain categories of tourism in the spread of IAPs. Tourism can also play a positive role, by making visitors aware of the threats of IAPs and the value of non-invaded, well-functioning ecosystems. Conservation agencies are increasingly required to become financially independent as government grants are redirected to other

areas of the economy. The different models and numbers of tourists in different PAs provide an exciting study system for exploring these questions.

- The transformation of habitat by IAPs from, for example, open woodlands and grassland to dense patches of alien woody shrubs (or vice versa), may potentially impact herbivore migration patterns. Could such changes, together with the combination of human encroachment on open boundary PAs and landscape fragmentation, impact on, for example, the iconic migrations of wildebeest (*Connochaetes taurinus*) and zebra (*Equus zebra*) in Serengeti NP and Tarangire NP and white-eared kob (*Kobus kob leucotis*) in southern Sudan? Similarly, the transformation of grasslands to impenetrable thickets of IAPs is impacting on feeding areas of the one-horned rhinoceros (Lahkar et al. 2011) and replacement of woody thickets by *Chromolaena odorata* (siam weed) displacing black rhino (*Diceros bicornis*, Howison 2009).
- A characteristic feature of many PAs is the presence of large numbers of mammalian herbivores. Large herbivores, in high numbers, have either been present up until recent decades or are still present. High populations of large mammals create disturbances of varying kinds and intensities, which could conceivably allow for invasion into natural areas, while alternatively certain species may be suppressed. While there have been some studies on the role that these animals play in preventing or promoting alien plant invasions (e.g. Constible et al. 2005; Rose and Hermanutz 2004) an improved understanding of interactions between such key elements of the native biota and IAPs is needed as a tool to facilitate the development of integrated PA management plans.

28.5 Conclusion

The chapters in this book show that the extent of invasions of alien plants is growing rapidly in PAs globally. The effects on biodiversity of PAs are already dramatic in many cases, and the overall impacts attributed to IAPs are increasing rapidly. Future trajectories are difficult to predict, as invasive species interact in complex ways with other factors of global change such as climate change, habitat loss and many forms of human pressure. The impact of IAS on PAs has long been underestimated, and the concerns raised by scientists more than 20 years ago that this threat was going to increase (Macdonald et al. 1989; Usher 1988) were largely ignored by national and international institutions.

Management strategies for IAPs (and invasive alien species in general) in PAs require urgent attention to avoid a rapid and irreversible escalation of impacts of the sort that are described on many pages of this book. Assuming that IAPs in PAs will look after themselves due to some natural processes (following the laissez-faire approach to PA management by some agencies) is not an option (Chap. 3 Meiners and Pickett 2014; Chap. 21 Meyerson and Pyšek 2014) and active management of this threat is crucial. Evidence-based policy and management, developed through rigorous science, will allow PAs to respond appropriately to this growing threat at all scales.

Protected areas can and should play a major role in combating invasions, not only by improving the efficacy of IAS management within their borders, but also monitoring patterns of invasions, raising awareness at all levels, improving the capacity of practitioners to deal with invaders, implementing site-based prevention efforts, enforcing early detection and rapid response frameworks, and catalysing action beyond the park boundaries. Protected areas must be more active in preventing and mitigating the global effects of invasions by being: reservoirs of the heritage of native species and ecosystems; sentinels of incursions to speed up response at all levels; champions of information and awareness with the different sectors of the society; and catalysts of action at all scales.

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